A METHOD OF SEPARATING NON-METALLIC MATERIAL USING MICROWAVE RADIATION

CROSS REFERENCE

This application, as permitted, is a continuation-in-part, a patent of addition or a certificate of addition, of International Application No. PCT/US2006/00742, filed 05 January 2006, which in turn, as permitted, is a continuation-in-part, a patent of addition or a certificate of addition, of International Application No. PCT/US 2005/026739, filed 18 July 2005.

TECHNICAL FIELD OF THE INVENTION

This invention generally relates to the physical separation of non-metallic materials into a plurality of smaller pieces. In particular, the invention relates to a method for splitting of a glass body, including laminated glasses.

BACKGROUND OF THE INVENTION

For manufacturing most products made of glass, laminated glass, semiconductor and other brittle non-metallic material, the separating of work stock into a number of smaller pieces of the desired size or size's is required. For example, many glass products are formed by a large sheet of glass separated into smaller pieces of the desired size.

There are two main ways to cut glass and similar materials. The first is cutting glass and other brittle substrates that includes abrasion or scribing by the use of mechanical cutting tools. For example, glass sheets have been cut by scribing the glass with a diamond-tipped scribe or a carbide wheel to weaken the molecular structure. After the scribe has been made, physical pressure is applied to create a force at the scribe line to hopefully break the glass along the scribe line.

Another way of splitting bodies of glass and like material into parts is to use the thermal shock process produced by intense local heating of the body. The use of different heat sources for said local heating is known from the art. The most common among them are laser (see, for example US Patent Nos. 6,420,678; 3,629,545; 4,468,534; 5,609,284), hot gas (5,394,505) or fuel (5,394,505) jets.

Both ways have significant disadvantages. One significant disadvantage is the inability to obtain smooth edges. This may be unacceptable for many products, for example displays or solar panels, because of the required quality of the edge faces. Accordingly, secondary steps such as grinding, edge seaming, and polishing may be performed. However, such secondary steps slow down the manufacturing process, can be expensive and still, very often do not meet the requirements of the edge quality.

Another disadvantage is that edge defects on some of these rough edges may result in crack propagation during further processing or in the ultimate product. The edge strength of the substrate is also reduced. Glass can contaminate the substrate being separated, and require that additional clean-up steps be performed to minimize their impact on the manufacturing process.

The main reason for all these problems is that all known cutting methods from the art create weakness on the surface and then the glass breaks. In the case of using heat, this occurs because all the above-mentioned heat sources heat materials from the surface and do not penetrate inside. As a result, the compressive stress is produced only in the ultra thin heated layer of the surface. This also limits cutting speed. The use of mechanical tools in addition, involves the expenditure of much time and skill, because they are basically manual. Besides, mechanical tools are subject to wear, and worn tools result in inconsistent and unreliable cuts.

Cutting laminated glass is especially difficult and has many problems because of the interlayer that resists separation of the body. The most common way to cut laminated glass is to score both sides of the laminate, and bend it first to one side and then to the other side, the two parts of the laminated glass being pulled apart while

performing the second bending step. The interlayer then is melted off simultaneously over the entire length of the parting line by a jet of heated air, flame, plasma etc. directed into the gap formed by the bending operation (see, for example, US Patents 5,944,244; 5,931,071; 5,704,959; 4,739,555; 4,558,622; 4,471,895 and 4,434,974). All known methods have the same problems as is described above for non laminated glass plus laminated glass requires more time and effort. It is impossible to cut laminated glass that contains more than two glass sheets by this approach.

Using a high pressure water jet (see US Patent 4,728,379) allows cutting thicker laminates, but it is very slow and messy and still results in poor quality edge faces.

Consequently, achieving very smooth cuts on brittle material, especially glass, is a significant challenge in industry. Therefore, there exists the need for a method of dividing or parting substrates of brittle non-metallic material that overcomes these and other problems. The main advantages of a high speed and high quality cutting method are increasing production rate and reducing manufacturing costs.

SUMMARY OF THE INVENTION

This invention generally relates to the physical separation of bodies of a brittle non-metallic material, preferably glass sheets and pipes, by a thermal shock process in which a microwave radiation is used for rapid and selective heating of a local area of the body. Materials which may be separated by the inventive method include ceramics, semi-conductor wafer materials, glass, fiberglass, quartz, and the like. Material treated by this method can be used in the production of automotive and aircraft glazings, of construction and architectural window glass and the like, of pharmaceutical glass products and the like, of semiconductor wafers and the like, and glass components of various household items and furniture, and the like, structural optical components, and the like, mobile device displays, solar panels, and also in other fields of production and technologies where precision cutting of non-metallic materials is conducted or desirable.

According to the present invention, a method is provided for the separation of bodies of a brittle non-metallic material, preferably glass sheets, by a thermal shock. The inventive method utilizes concentrated microwave radiation to rapidly and selectively heat the local area of the body to be thermally separated (e.g., a glass sheet, a glass pipe).

In the inventive method a concentrated microwave radiation with appropriate frequency and power density is chosen so as to accomplish heating of at least one selected area of the body at the required separating propagation path to the required temperature in a selected short time while insuring that this temperature is large enough to create a thermal stress through the thickness of the selected area which thereby results in the separating of the body material.

The inventive method avoids the use of existing mechanical and thermal tools that are slow and dusty and do not provide a high quality of cut. The present invention includes making the process easily adaptable for many applications, achieving fast cutting speeds and total separation of the substrate, obtaining smooth edges, and eliminating the need for secondary operations. Any kind of brittle material including those having low thermal expansion can be separated by the inventive method.

The main advantages of this high-speed method are the ability to cut a wide range of thicknesses (from super thick, more than 20mm to ultra thin, less than 1mm), high quality (dustless, chip and stress-free) and accuracy, reducing manufacturing costs and increasing production rate. Many other specific advantages also exist including but not limited to cutting complex shapes, the elimination of the cost and issues of grinding, transporting and transferring cut parts for grinding, cleaning cuts.

Accuracy and cutting speed can be increased if an additional heat source with a power distribution that is significantly sharper than in the applied concentrated

microwave radiation follows or is applied simultaneously or before the body's exposure to microwave. In this case, this additional heat source creates a sharp maximum of thermal stress just on the propagation path that reduces the deviation of separating line along the propagation path. This allows also an increase in the cutting speed. The said additional source is selected from the group consisting of laser, gas torch, microwave, and other sources of concentrated energy.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 schematically illustrates the temperature profile and compressive stresses that are produced inside a glass sheet when it is irradiated by concentrated microwave radiation.

FIG. 2 schematically illustrates a method for cutting, with simultaneous cooling in accordance with one embodiment of the invention .

FIG. 3 illustrates the compressive stresses that are produced inside a glass sheet when it is irradiated by an elongated microwave beam.

FIG. 4 illustrates a method in accordance with the teachings of the method of the present invention for cutting laminated glass with an elongated microwave beam that has different power density at its front and back.

DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to a method of thermally separating a brittle non-metallic material, preferably a glass sheet, by a thermal shock. In the inventive method a microwave radiation with appropriate frequency and power density is used.

In all of the embodiments of the invention, the frequency (wavelength) of the concentrated microwave and power density of the applied microwave radiation are important parameters of the inventive method which must be determined for each type of body material and thickness of bodies processed. The process parameters are chosen so as to accomplish heating of selected area of a body at the required separating propagation path to required temperature in a selected time such that the difference in this temperature and the temperature of the rest of the body material is large enough to create a thermal stress that results in the separating of the body material in the heated area. In the inventive method said stress is created not only on the surface but through the thickness as well. Flat, non-flat, and pipe types of bodies can be separated using the inventive method.

These parameters and how they are chosen are generally described below for the embodiment of the invention in which a flat glass sheet is exposed to microwave radiation. However, it is understood that the same parameters and their choices are applicable to and must be considered in the alternative embodiments of the invention: cutting glass pipes, semiconductor materials, and like.

The inventive method is generally applicable to the thermal separation of any type of brittle non-metallic material. These treatments include but are not limited to the glass sheet employed in the production of windshields, side windows, and rear windows for vehicles such as automobiles and the like, the production of architectural window glass and related materials, the production of pharmaceutical glass products such as vials, ampoules, pipettes, and the like, display glass for mobile devices, solar panels, and the like, glass components of various household items and furniture, and the like, fiberglass and the like, as well as, semiconductor materials employed in the production of semiconductor wafers and the like.

The cutting of glass, under the action of thermal stresses, consists of the following. When concentrated microwave radiation (microwave beam) **1** (see Figure 1) is applied to a selected area **2** at the required separating propagation path **3** of the glass sheet **4**, the concentrated microwave radiation **1** passes through the glass sheet and heats the area throughout the depth. Curve **5** illustrates the temperature profile inside the glass sheet **4** that is created by this heating. Compressive stresses **6** are produced in the material being heated because the surrounding areas remain under lower temperature, as well as, surface temperature reduction just after heating under cooling by cold ambient air. The splitting of the plate glass occurs when these thermally-induced stresses exceed glass tensile strength.

While the tensile strength is determined primarily by the characteristics of the glass being processed, the compressive stresses can be increased because they mainly depend on the volume of the glass that is heated up, and the temperature gradients in and around the heated area. The rate of thermal splitting (cutting speed) in turn is dependent on how rapidly appropriate compressive stresses are created. All this means that the selected area should be heated throughout the thickness and it should be heated rapidly and to a high enough temperature. These conditions can be satisfied by the selection of effective microwave frequency and sufficient power density.

The particular frequency chosen should ensure the heating of the selected glass sheet area throughout the thickness of the glass sheet with maximum coupling of the incident microwave energy in the area. In addition, the chosen frequency should be cost effective and microwave generators for the selected frequency should be readily available at the required power.

We found that the frequency range of microwave energy that meets these requirements for most actual thicknesses and material properties where the inventive method can be applied is in the gigahertz range. However, the necessary power density drastically rises if the microwave frequency is lower than 10 GHz, and creates many technical and economic problems. Therefore a higher microwave frequency is more preferable. On the other side, the current state-of-the-art level of microwave technique makes it very difficult and expensive to install a power system with a frequency higher than 1000 GHz. Thus, the effective microwave frequency range for the present invention is between about 10 GHz and about 1000 GHz. The preferable frequency is such that the skin layer for this frequency in the body material approximately equals its thickness. In this case, heating across the thickness is guarantied.

In the embodiments of the invention discussed above, a microwave absorbent, having a greater microwave absorption than the body material at a selected microwave irradiation frequency, is applied along the required separating propagation path. This allows increasing the cutting speed and accuracy because higher absorption increases the heating rate.

Heating rate increases more if microwave irradiation frequency is selected such that the skin layer for this frequency in the absorbent approximately equals its thickness. The absorbent is selected from the group consisting of semi-metals, carbides, nitrides, oxides, sulfides, silicides, boron, carbon, graphite and metals.

Cutting speed increases also if selected heated area and its surrounds of the body of material are cooled during exposure to microwave, as well as, before and after exposure, because this increases compressive stresses. A stream of cold gas 7 (see Figure 2), for example, liquid nitrogen steam that blows on the body, can be used for said cooling because gases are transparent to microwave. The body can be cooled by placing it on a cooled metal support and/or by placing a cold correspondently shaped plate on the surface that is exposed to microwave. The material of said plate is transparent to microwave and is selected from the group consisting of oxide ceramics, nitride ceramics, quartz and diamond.

Accuracy and cutting speed can be increased if the exposure to concentrated microwave radiation is conducted through a metal mask with an opening along the required propagation path.

It has been further found that maximal speed can be achieved by irradiating applied absorbent and/or irradiating through the mask, all at once.

Making a short scribing just at the edge on the glass surface makes the glass parting start more easily and more accurately, without losing the quality of cutting.

In the embodiments of the invention discussed above, an applied concentrated microwave radiation (microwave beam) 1 (see Figure 3) is elongated in the direction of the required separating propagation path 3. This allows increasing the cutting speed and accuracy because it creates higher compressive stresses, 6. The compressive stress increases also by moving the microwave beam during cutting along the separating propagation path from the beginning to the end and back at least two

times. The beam power density and moving speed are selected sufficient to separate of the body material in the selected number of moves.

In the embodiments of the invention discussed above a microwave beam during the cutting of laminated glass moves at least two times along the separating propagation path from the beginning to the end and back. The beam power density during at least the first time, is selected sufficient to selectively eat polymer adhesive film to its delaminating temperature (around 80C-110C) along the separating propagation path before being followed by the step of separating of the glass body.

In the embodiments of the invention discussed above, cutting laminated glass is provided by an elongated microwave beam, in the direction of the required separating propagation path 3 (see Figure 4), with different power density in the beam at the front 8a and the back 8b. The beam length, power density at its front, and speed are selected to be sufficient to heat polymer adhesive film 9 to its delaminating temperature (around 80C-110C) before being followed by the step of separating of the glass body.

Concentrated microwave radiation with the necessary frequency and power density can be achieved using generators such as the gyrotron, klystron, traveling wave tube, and backward wave oscillator, and the like.

Accuracy and cutting speed can be increased if an additional heat source with a power distribution that is significantly sharper than in the applied concentrated microwave radiation follows or is applied simultaneously or before the body's exposure to microwave. In this case, this additional heat source creates a sharp maximum of thermal stress just on the propagation path that reduces the deviation of separating line along the propagation path. This allows also an increase in the cutting speed. The said additional source is selected from the group consisting of laser, gas torch, microwave, and other sources of concentrated energy.

The main distinctions of the inventive method are high cutting speed, quality of cut, and range of thicknesses that can be cut, as well as, eliminating the need for secondary operations. Any kind of brittle material including those having low thermal expansion can be separated by the inventive method.

The present invention has been described in an illustrative manner. It is to be understood that the terminology that has been used is intended to be in the nature of words of description rather than of limitation. Many modifications and variations of the present invention are possible in light of the above teachings. Therefore, within the scope of the appended claims, the present invention may be practiced other than as specifically described.